Contract Number
DACA42-02-C-0003

Southern Maryland Electric Cooperative
Michael Rubala, Energy & Technology Programs Manager

SMECO/Navy PEM Fuel Cell Demonstration

Proton Exchange Membrane (PEM) Fuel Cell Demonstration
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers
Engineer Research and Development Center
Construction Engineering Research Laboratory
Broad Agency Announcement CERL-BAA-FY01

Patuxent River Naval Air Station
Patuxent River, Maryland

May 23, 2005

Executive Summary

Southern Maryland Electric Cooperative (SMECO), Hughesville, Maryland was awarded a CERL grant to demonstrate two PEM fuel cells at Patuxent River Naval Air Station (PRNAS), Patuxent River, Maryland. One fuel cell unit was supplied by natural gas and the other by propane gas as the reformer fuel for Hydrogen extraction. The manufacturer of both units was Plug Power of Albany, New York. This project represented a first for Plug Power in that one of their first propane reformer units were to be field tested and both fuel cells were to operate at a 5 kW setting for most of the twelve-month demonstration period. This demonstration's intent was to field test two fuel cells in actual world environments at a kW output level more representative of typical loads for both residential and small commercial applications.

Both units were installed in early January 2004 and were successfully operated for the entire twelve-month period without any lengthy down time. The propane unit was connected to a small commercial-type building, which housed the base environmental and conservation personnel. The basic loads the fuel cell supported included nine desktop computers, office lighting, oil furnace, and life support systems for animals on display. The unit was grid connected and whenever house meter load was less than fuel cell output, the excess power was transferred to the grid. This unit operated one month at 4 kW output, two months at 2.5 kW output and nine months at the 5 kW output setting. Co-generated heat energy was captured off the fuel cell stack and used to provide first stage heat for the building. During non-heating periods the co-generated heat was sadly rejected to the atmosphere, for this facility had no need for heat other than for the winter months.

The natural gas unit was connected to a residential building located along the shore of the Chesapeake Bay. The basic loads this unit supported were lighting, boiler and pumps, refrigerator, kitchen counter receptacles, and sump pump. This unit was also grid connected and whenever house load was below output, the grid received fuel cell power. This unit operated at 2.5 kW for two months and ten months at the 5 kW output. Co-generated heat energy was captured and used the entire year to pre-heat the potable cold water supply for the water heater.

The costs of operating the two units were quite different. Natural gas fuel and distribution charges for base facilities are based on a single block rate of \$1.30/therm. Over the course of twelve months the natural gas unit consumed 4,945 therms for a total cost of \$6,428.99. The overall production efficiency (avg.

electrical efficiency + avg. thermal efficiency) was 27.27%. The propane costs escalated substantially from project conception to decommissioning. Original costs for propane was calculated to be $1.35/gallon but prices quickly rose to $1.65, then to over $2.00/gallon at the end of the test. Overall propane fuel costs averaged $1.73/gallon. The propane fuel cell consumed 6,235 gallons at a total cost of $10,786.55. The overall production efficiency was 36.21%.

Both units performed well at the consistent 5kW maximum output setting. The service availability for the natural gas unit was 95% and the propane unit was 91%. The electrical generation efficiency for both units was relatively close to fossil fuel central plant distribution efficiency of 30 to 35%. Without adding co-generation usage benefits, the natural gas fuel cell electrical generation average efficiency was 23.65% and the propane unit was 22.36%. When accounting for co-generation, the efficiencies jumped for some months to as high as 68%. Utilizing co-generation waste heat is the key to maximizing performance and efficiency. Though this demonstration was costly, and the units demonstrated were not commercially viable, information gathered will definitely help the effort in creating an eventual hydrogen economy.

Table of Contents

1.0 Descriptive Title

SMECO, with support from Navy officials, installed and operated two Plug Power GenSys 5 kW fuel cells at Patuxent River Naval Air Station. One fuel cell had a natural gas reformer for extracting hydrogen and the other had a propane reformer. Both units were to operate at the maximum 5 kW output for most if not the entire twelve-month period. Both units were also grid connected so excess output was sent back onto the grid.

Site 1 was a single family home piped with natural gas. It was agreed this site was a good residential representation of natural gas-fitted homes on the base. The fuel cell was placed next to the garage and a fence installed around it. All power cables, control wiring, de-ionized water, and co-generation piping was buried underground. The sub-panel, Btu meter, co-generation loop pump, and water de-ionizer were placed in the house basement. The co-generation loop was connected to an indirect water heater to receive hot water from the fuel cell and, in turn, heat potable water prior to it entering the main water heater, which is gas fired. The sub-panel was wired so all excess electricity generated went onto the grid and also served as emergency back-up in the event of a power outage.

Site 2 is a small office building used by the base natural conservation personnel. It was agreed this site was a good office environment representation. A 500-gallon propane tank was installed allowing for three- to four-week intervals between fuel deliveries. The fuel cell was placed next to the north side of the building. We selected this facility since it is open to the public and we could display the fuel cell easily to those entering the building. All power cables, control wiring, de-ionized water, and co-generation piping was buried underground at this site as well. The sub-panel, Btu meter, co-generation loop pump, and water de-ionizer were placed in the utility room. The co-generation loop was connected to a hot water coil placed in the supply plenum of the oil furnace. This hot water coil served as the first stage heat for the building. The sub-panel was wired so all excess electricity generated by the fuel cell was sent to the grid. This connection also served as an emergency back up in the event of a power outage.

2.0 Name, Address and Related Company Information

Plug Power, Inc.
968 Albany Shaker Road
Latham, NY 12110

Michael Doud
Site Development & Installation Coordinator
Ph. 518-782-7700, x1440

Brian Davenport
Product Development
Ph. 518-782-7700, x1939

3.0 Production Capability of the Manufacturer

Plug Power, a New York State designer and manufacturer of Proton Exchange Membrane (PEM) fuel cells has extensive experience in the design and operation of PEM fuel cell systems since its inception in 1977. Plug Power produces both natural gas and propane type PEM fuel cells. Plug power has provided PEM fuel cells to New York State Energy Research and Development Authority, General Electric, DTE Energy Technologies, and the Long Island Power Authority. Plug Power has operating experience in PEM fuel cell systems of over 250,000 hours in laboratory, field demonstration, and prototypical environmental applications. Plug Power is now in full commercial production of telecom fuel cells for remote site power supply.

4.0 Principal Investigator(s)

Michael J. Rubala, CEM
Energy & Technology Programs Manager
Southern Maryland Electric Cooperative, Inc.
P.O. Box 1937 Hughesville, MD 20637
301-274-4338
301-274-4455 fax
mike.rubala@smeco.coop

Michael Oliver
Utilities Engineer, Public Works Department
Patuxent River Naval Air Station
22445 Peary Road
Patuxent River, MD 20670
301-757-4723
301-757-4944 fax
michael.oliver@navy.mil

5.0 Authorized Negotiator(s)

Michael J. Rubala, CEM
Energy & Technology Programs Manager
Southern Maryland Electric Cooperative, Inc.
301-274-4338
301-274-4455 fax
mike.rubala@smeco.coop

5.0 Host Facility Information

Host facility is Patuxent River Naval Air Station (PRNAS) located in Patuxent River, Maryland. Geographically, the base is along the western shore of the Chesapeake Bay and the mouth of the Patuxent River. The base is a modern facility used for U.S. Navy flight test and evaluation of all aircraft used by the fleet. The base soon will be home to the testing of the new joint fighter to be used by all branches of the armed forces and most NATO nations. The base employees over 20,000 military and civilian personnel. Southern Maryland Electric Cooperative provides electric transmission service to the base and natural gas is provided by Washington Gas.

7.0 Fuel Cell Installation

Site preparation for both fuel cell installations occurred in the fall. Both sites were ready for fuel cell arrival by December 1. Both fuel cells arrived on base and were set on their respective pads at the end of December 2003. Plug Power commissioned the natural gas fuel cell at site 1 on January 7, 2004 and the propane fuel cell at site 2 was commissioned on January 14, 2004. Due to weather conditions, actual on-site labor varied and at times was interrupted. Man hours for site 1 for plumbing was approximately 32 hours and electrician was approximately 48 hours. At site 2, the plumber man-hours were approximately 26 hours, electrician 50 hours, and HVAC technician 8 hours. All contractors involved commented on the learning curve required for certain aspects of the installation and on the difficulty of installing plumbing and wiring in existing buildings or excavating in established landscaping.

Site No. 1 Preparation

Site No. 1 is the installation of the natural gas PEMFC unit at a private residence along the Chesapeake Bay shoreline. Navy officials requested the fuel cell be placed about sixty feet from the house. Wiring and plumbing had to run an additional twenty feet of length within the home. Total length of piping and wiring was approximately 80 feet. Two trenches were provided from the house to the fuel cell. One trench was for the natural gas pipe. The second trench was for power and control wiring, deionized feed water, plus a supply and return water pipe for co-generation use. Below are photos of the trench, pad preparation, building interior wiring and plumbing connections, and PEMFC being off loaded and prepared for operation.

Site No. 1 (Quarters Y) Installation

Trenching across the yard

- *One trench was provided for the natural gas pipe leading from the house gas main to the fuel cell pad.*
- *The other trench was for power and control wiring, supply and return co-generated hot water, and the de-ionized feed water.*

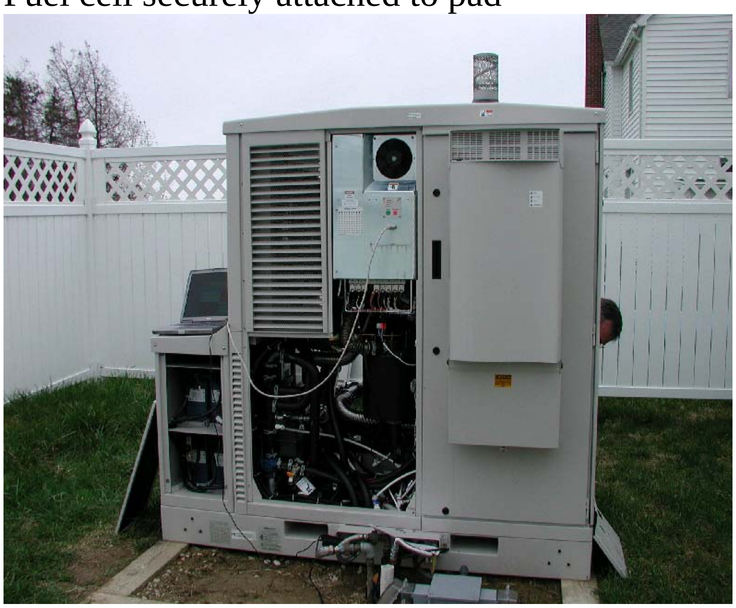
Pad with utility stub-ups

- *Fuel Cell support foundation is made up of pressure-treated 6x6 timbers, all resting on a six-inch-thick gravel bed.*
- *All piping and wiring conduits terminate at the pad.*

Fuel cell off loaded by boom truck

- *The Plug Power fuel cell could be off loaded by a boom truck or a forklift.*
- *Once lowered on the pad, all plumbing and wiring connections are made in a relatively short time.*

Fuel cell securely attached to pad



- *Once the plumber and electrician complete all connections, a PlugPower technician secured all fittings that may have come loose during shipping.*

Installation complete at Site No. 1

Note: During initial start-up procedures, the fuel cell took longer to achieve proper operating temperatures due to cold winds blowing off the Chesapeake Bay. The fence was added later for visual reasons.

Site No. 2 Preparation

Site No. 2 is the installation of a propane-fueled PEMFC at the PRNAS Conservation building. This site was selected for its intrinsic value as the focal point for all base environmental endeavors. The building houses a classroom used by the public for conservation programs and offices for employees. The building also is the home for many live animals on display for educational purposes. This building was an ideal location for a propane-supplied fuel cell. During construction we took special precautions in regards to public safety. We fenced off the area from curious onlookers and covered open trenches during non-construction periods. The placement of this fuel cell is much closer to the building as compared to site No. 1. A single trench for wiring conduits, co-generated hot water pipes, and de-ionized feed water is only fifteen feet in length. All connections inside the building are within five feet from the exterior wall penetration. An additional trench was provided for the propane fuel pipe running about 70 feet to an above ground 500-gallon storage tank. Below are photos of the utility stub-ups, pad preparation, building interior wiring and plumbing connections, and PEMFC installation.

Site No. 2 (Conservation Building) Installation

View of the PRNAS Conservation Building

- *The base Environmental Protection and Conservation building was selected for its easy access by the public and load requirements suitable for the 5.0 kW fuel cell.*

- *Site was also suitable for propane storage and a co-generated heating application.*

Trench and stub-ups prior to pad installation

- *Here the stub ups for all connections are easily seen.*

- *This area is open to the general public and had to be fenced off and covered each night for safety.*

- *After backfill, a 6-inch gravel base was added and a 6x6 timber foundation installed.*

Pad installation and trenching complete

- *The 6x6 foundation has been installed.*
- *All trenching and backfill work complete.*
- *There is a trench leading from the 500-gallon propane tank 70 feet to the fuel cell location. Propane for the fuel cell is provided at a 20-psi pressure level.*

Fuel cell stack being installed

- *The equipment room is located 15 feet from the fuel cell location with easy access for public viewing during planned educational programs.*
- *Being a commercial building, all power and control wiring required proper conduits and support.*
- *Technicians installing the stack, which was quick and easy.*

Circulator pump

- *In the center of the picture is the co-generation water loop circulator pump. The flow was measured at 3.8 gpm.*

Culligan feed water filter and de-ionizer

- *To the left of the first stage filter is the EPA-required back-flow valve. This is required to prevent a contamination of the public water supply by the fuel cell via the feed water connection.*

- *The de-ionizer must maintain conductivity less than 1.0 microseism. This must be checked every 6 months.*

Preparing fuel cell for operation

- *A technician prepares the fuel cell by connecting all wiring and plumbing connections.*
- *All connections were made in less than four hours.*

Finished installation at site No. 2

The propane unit was fully installed and running in less than two days. We had gravel spread around the unit to accommodate the many footprints of onlookers. The drainpipe was installed to facilitate proper drainage around the gravel base. It is a short fifteen feet to the equipment room located just behind the door under the lamp on the building wall. This provides safe and easy access to the co-generation connections, critical load panel, and feed water de-ionizer.

Prior to fuel cell commissioning, the base Environmental Office and Fire Department had to approve certain aspects of the installation. The Environmental Office required the co-generation heat exchange fluid to be EPA approved food grade non-toxic antifreeze and the potable water heat exchanger to be double walled. They also required the de-ionized water supply, which was connected to domestic city water tap, to be protected with a back flow device. The Fire Department inspected propane and natural gas fittings and cut off valves prior to commissioning.

8.0 Electrical System

Both units were installed with the intent to operate the fuel cell stacks at the maximum 5 kW output limit. Both units were wired to be grid parallel. The fuel cell inverter provided utility grade voltage, synchronization, and fault disconnect protection. The fuel cell power output could provide critical load support during a utility outage and generate onto the grid when stack output exceeded system load. The 5 kW stack output was set for continuous loading conditions with battery power reserve to handle inrush current for motor starts or overall short-term system load increases. Battery bank augmented the stack output for up to 15 kW depending on the load demand duration and occurrences. Never did the inverter kick the fuel cell off line for overload power conditions. However, we did experience over voltage operation and multiple disconnects during a several-week period by the inverter. It was discovered to be caused by the grid system neutral connection, which had been damaged during a previous storm.

Load Center & Grid Parallel Panel Served By Fuel Cell

- *The small panel is the critical load supplied by the fuel cell.*

- *The Fuel Cell will be set at 5 kW output and will be in parallel with the utility grid.*

- *The load center is wired to accommodate net metering whenever the critical load panel is below 5 kW in demand.*

- *Critical load can be supplied by the Fuel Cell in the event of a utility outage.*

Site 1 Loads:
The critical load panel supported by the fuel cell provided power to the following circuits:

- Interior lighting in several rooms
- Refrigerator
- Natural gas boiler and circulator pumps
- Kitchen counter receptacles
- Basement sump pump
- Co-generated heat loop circulator pump
- Btu meter
- Heat tape for exposed ionized water pipe at Fuel Cell

The Plug Power limitation of 120 vac/42 amps steady state availability dictated what loads could be supplied by the fuel cell. All household 240 vac loads were beyond the fuel cell capacity even with a 120/240 transformer installed. Thus we wired the most critical 120 vac appliances to the fuel cell power supplied panel. This scheme would provide emergency power (5 kW limit), in the event of an outage, to the refrigerator, boiler and lights. Wiring the load center as a grid parallel application also enabled all excess-generated electricity to be put back onto the grid. This was the first application on the base of a distributed generation process. The load profile of a typical natural gas-supplied residential home illustrates there are many hours the load is less than 1.5 kW. Indeed, the fuel cell generated a capacity of 4 kW onto the grid for many hours per day. The hourly average for the test period, provided by PRNAS metering data, shows 1.92 kWh were generated back onto the system. That equates to 1,384 kWh per month or $124.61 at the off-base retail rate.

Site 2 Loads:
The critical load panel supported by the fuel cell provides power to the following circuits:

- Building interior lighting
- Nine desk-top computers
- Animal display life support systems (air pumps and heaters)
- Oil forced air furnace
    - Blower and burner in winter
    - Blower only in summer
- Co-generated heat loop circulator pump
- Btu meter
- Heat tape for exposed ionized water pipe at Fuel Cell

The average load is between 3.0 and 3.5 kW, which is an ideal load for the fuel cell stack. Even better is that being a commercially operated building, the energy load is relatively consistent eight to ten hours per day. This consistent 75 to 80 percent stack loading maximizes fuel cell stack efficiency and reduces internal processing stresses according to Plug Power.

PRNAS Metering Readings for site 1 & 2

Site 1 Natural Gas Unit

Date	KWh	# of days	kWh / day	Historic Average	0utput kWh /day
01/07/04	18927	-	-	30	
02/10/04	18839	33	-2.67	30	
02/17/04	18163	7	-96.57	30	126.57
03/04/04	16756	17	-82.76	30	112.76
03/22/04	15624	18	-62.89	30	92.89
05/07/04	14825	45	-17.76	30	47.76
06/07/04	13462	30	-45.43	30	75.43
06/15/04	13120	8	-42.75	30	72.75
06/29/04	12464	14	-46.86	30	76.86
07/20/04	11826	21	-30.38	30	60.38
08/27/04	10819	37	-27.22	30	57.22
10/08/04	8326	41	-60.80	30	90.80
11/30/04	5165	52	-60.79	30	90.79
12/22/04	4648	22	-23.50	31	54.50

Site 2 Propane Unit

Date	kWh	# of days	kWh / day	Historic Average	0utput kWh /day
01/14/04	81580	-	-	90	
02/10/04	81607	26	1.04	90	
02/17/04	81852	7	35.00	90	55.00
03/04/04	82616	17	44.94	90	45.06
03/22/04	83265	18	36.06	90	53.94
05/07/04	85922	45	59.04	90	30.96
06/07/04	87809	30	62.90	90	27.10
06/15/04	88166	8	44.63	90	45.38
06/29/04	88795	14	44.93	90	45.07
07/20/04	89696	21	42.90	90	47.10
08/27/04	91822	37	57.46	90	32.54
10/08/04	93922	41	51.22	90	38.78
11/30/04	97222	52	63.46	90	26.54
12/22/04	98381	22	52.68	91	38.32

NOTE: Negative kWh/ day reading designates excess power generated by the fuel cell onto the grid. Every day on average for the entire year at some time of the day the fuel cell exceeded power demand by the resident load. The commercial load at site 2 was much greater, resulting in zero grid power output but historical daily kWh consumption was reduced from 25 to 45% on average.

9.0 Thermal Recovery System

Site 1 co-generation recovery was connected to the domestic hot water system as a pre-heater to the main tank. The existing system was a 40-gallon vessel surrounded by a separate heating jacket, which received circulated hot water off the gas boiler. The pre-heat tank was a like vessel installed and plumbed directly into the cold water feed side of the main hot water tank. The pre-heat tank’s separate heating jacket circulated the hot co-generated fluid (>125 degrees F) collected from the fuel cell, thus pre-heating supply water to the main tank. This method served its purpose well; the sad part is the residents put a very low demand on the domestic hot water supply. During the initial design stages, the residence was occupied with a family of five (two adults and three teenagers) but they relocated just prior to the fuel cell commissioning. The new occupants were two adults that traveled some and put marginal use on the water heater. The chart below illustrates the low heat recovery rate equating to a low thermal efficiency. The designed installation worked very well; unfortunately the residence simply did not put enough demand on the available co-generated heat collected from the fuel cell. Most of the co-generated heat was simply rejected to the outdoors.

Site 1 Co-generation Efficiency

Month	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency (%)	Overall Efficiency (%)
January, 2004	189100	344.4	0.57%	25.23%
February, 2004	1073747	1542.7	2.75%	33.04%
March, 2004	1558545	2176.0	3.97%	24.81%
April, 2004	1351304	2036.0	6.99%	27.10%
May, 2004	1723304	2398.2	3.48%	26.47%
June, 2004	1492000	2083.8	2.87%	26.04%
July, 2004	1630000	2199.7	3.23%	25.49%
August, 2004	1338000	1922.4	2.88%	25.57%
September, 2004	1855000	2576.4	3.57%	27.19%
October, 2004	1609000	2364.8	3.76%	27.17%
November, 2004	1610000	2286.9	5.36%	30.16%
December, 2004	1084000	2068.7	5.85%	29.96%
January, 2005	989000	2943.5	8.97%	34.99%

Site 1 Co-generated Heat recovery Tank

- *This vessel served as a preheat tank for the domestic water heater.*
- *The circulating pump operates at a 3.5 gpm flow rate.*
- *This was a closed loop design using a non-toxic food-grade anti-freeze solution as a heat transfer medium.*
- *Preheated water entered the main water heater tank at temperatures above 125 degrees F.*

The Site 2 installation was a little more complicated and more effective in utilizing the co-generated heat. Site 2 fuel cell installation was engineered to expose the fuel cell to a relative steady load requiring stack output at or above 75-to 80-percent capacity. This loading scheme generated a nominal 22,000 Btu's per hour of available co-generated heat. The site 2 building's only need for thermal energy was for space heating. The decision was made to incorporate the co-generated heat source with the existing oil fired forced air furnace.

The base HVAC contractor installed a two-stage thermostat to provide proper control using two different heating sources. The two-stage thermostat will toggle between first stage fuel cell co-generated heat supply and second stage oil combustion in response to the building's space heating requirements. The circulator pump is powered by the fuel cell (no grid connection) via a line voltage relay off the first stage thermostat. When the first stage is activated, the furnace blower and circulator pump are energized, allowing co-generated hot water into the plenum-inserted heat exchanger. Should the heat output from stage one be insufficient, room temperature would continue to drop. If the room temperature dropped greater than two degrees F from stage one set point, the second stage would engage ignition of the oil burner and disengage the circulator pump.
We determined that whenever the ambient outdoor temperature was above a nominal 45 degrees Fahrenheit, the first stage heat (fuel cell co-generated Btu's) satisfied the building heating requirements exclusively. Generally, below 45 degrees the second stage would engage due to a two-degree drop in building temperature below the first stage setting. The thermostat would cycle between first and second stage until outdoor temperatures rose above the nominal 45 degrees again. The average winter temperature at PRNAS is 42 degrees Fahrenheit, making this a good location for this type of application. Recorded first-stage heat output (fuel cell co-generated output measured in the supply air stream) averaged around 106 degrees Fahrenheit. The return averaged around 75 degrees Fahrenheit for a delta temperature rise of 31 degrees. That is a respectable heating performance output from the fuel cell.

During the months of combined maximum fuel cell output and maximum co-generated heat utilization, the thermal efficiency and overall system efficiency skyrocketed. Site 1's highest thermal efficiency was only 8.9% compared to site 2's highest thermal efficiency of 37.4%, which reflects a much higher thermal utilization. Site 1's overall system efficiency peaked at 34.9% compared to site 2's peak of 68.6%. Overall efficiency is the combination of electrical generation efficiency and thermal recovery efficiency demonstrating the fuel cells' overall operating efficiency. It became very clear over the course of one year that both units performed well and were on line more than 90% of the time. But in order to maximize the fuel cells' overall energy production value, maximizing the co-generated thermal energy is clearly the driving force.

Site 2 Co-generation Efficiency

Month	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency (%)	Overall Efficiency (%)
insert month	*insert heat recovery*	*5	*6	*7
January, 2004	584100	1445.8	2.66%	27.56%
February, 2004	12534602	18009.5	37.29%	68.67%
March, 2004	15686255	21606.4	32.02%	53.95%
April, 2004	5166522	7620.2	9.77%	30.99%
May, 2004	1206521	2711.3	4.42%	25.99%
June, 2004	18000	26.5	0.04%	23.00%
July, 2004	7000	9.9	0.01%	21.81%
August, 2004	2000	2.8	0.00%	21.90%
September, 2004	1000	1.6	0.00%	22.32%
October, 2004	6379000	10811.9	12.59%	32.53%
November, 2004	13485000	20978.5	47.07%	66.66%
December, 2004	9517000	12808.9	33.51%	54.85%
January, 2005	4800000	14285.7	37.42%	59.78%

Co-generated heat exchanger attached to furnace

- *A hot water coil was installed into the supply-side plenum of the oil furnace.*
- *Co-generated hot water collected from the fuel cell stack is circulated through this coil via a circulating pump with a 3.8 gpm flow rate.*
- *A two-stage thermostat wiring control provides proper heating control between the hot water coil and furnace output.*

10.0 Data Acquisition System

Data acquisition was gathered from several access points and using several different methods. The fuel cell's on-board computer was equipped with a modem and each site provided phone dial-up connection. Every day at midnight, the fuel cell would download data to Plug Power pertinent to performance and operation of the unit. This also was the primary method used to determine when service was required and for what reason. This monitoring method proved to be very efficient and convenient, and went a long way in preventing complaints from site building occupants. During the course of the entire year there, was a perceived equipment malfunction that was identified but could not be found. This created some power fluctuations for the building occupants. It was eventually discovered that the utility neutral connection had been damaged in a severe storm.

Each site had a Btu monitor installed to gather co-generated heat use provided and used. This monitor measured the fluid temperature of both supply and return co-generated recovery loop. It also recorded flow rate and thus could calculate Btu's utilized by the co-generated heat application. This meter was read at the end of each month and data provided to Plug Power to be inserted in the monthly performance report. The building utility electric meter, natural gas meter, and gallons of delivered propane were also collected manually each month.

Major parameters monitored/recorded for each fuel cell:

Hours of operation
Energy produced kWh
Average output kW
Fuel usage
Thermal heat recovery Btuh
Gas leakage monitor
Reformer pressures and temperatures
Stack voltage and amperage
Stack moisture levels
Fuel pressure
Associated fan and pump operations
Internal coolant levels and temperatures
System operating pressures and temperatures
Inverter and battery bank conditions
Utility connection
Feed water supply volume

Whenever Plug Power noticed system operation out of acceptable parameters, Logan Energy was dispatched promptly. Logan Energy technicians usually arrived on the scene within 24 hours to repair the unit, thus avoiding long unnecessary shutdowns. Rarely did either fuel cell go into a self-shut down mode due to a more severe issue. Most shut downs by the fuel cell were caused by events outside of the fuel cell. Loss of propane or natural gas pressure or feed water supply were the main causes of all emergency shut downs.

11.0 Fuel Supply System

Site 1 fuel cell reformer required natural gas for the unit's supply of hydrogen. The connection was exactly like any freestanding emergency generator. The plumber experienced no problems installing the fittings and piping, nor did the base inspector have any problems passing the installation. The same can be said for the site 2 propane unit. A standard 500-gallon propane tank was set on the ground 70 feet from the fuel cell. The distance was more for aesthetics than anything else. The gas pipe from the tank to the fuel cell was buried and connected in normal fashion. Overall fuel connections were simple and straightforward. Fuel interruptions were the only unforeseen problems. During the course of the year, site 1 natural gas unit shut down due to gas distribution interruptions. Site 2 propane unit shut down three times when the tank was not refilled promptly. The first outage was due to a learning curve as to expected consumption when the stack was ramped up to the 5 kW output level. The supplier's scheduling mistakes caused the other two outages.

12.0 Program Costs

Program costs, in general, were within budget estimates. The only exception was the ever-increasing propane costs over the year and the higher than expected propane consumption. Before the project installation began, costs for propane were projected by the supplier not to exceed $1.35/gallon. But over the one-year demonstration period, propane escalated to a yearly average of $1.73/gallon. Propane consumption was estimated to be about 3,700 gallons, but the year-end usage was actually 6,235 gallons. The total cost of fuel consumed for the total kWh's generated to acquire a $/kWh cost is listed below:

Generation costs without thermal recovery applied

	Cost of fuel	kWh's generated	$/kWh
Site 1 **	$6,429	33,508	$0.19/kWh
Site 2 *	$10,787	32,819	$0.32/kWh

*** Base Utilities rate charges to PRNAS activities $1.30/therm*

** Yearly average propane --- $1.73/gal*

Generation costs with thermal recovery applied

	Cost of fuel	Thermal recovery	$/kWh
Site 1	$6,429	($284)	$.18/kWh
Site 2	$10,787	($1,143)	$.29/kWh

Thermal recovery value represents captured co-generated heat that replaced fuels that otherwise would have been purchased.

Site 1 Project Itemized Costs	**Projected Costs**	**Actual Costs**
Plug Power System Lease Cost	$50,000	$40,000
Service contract (replacement stacks)	$15,000	$15,000
Installation (labor & materials)*	$12,000	$3,550
Thermal Recovery (pre-heat tank)	$640	$640
Performance Monitoring	$1,200	$1,156
Maintenance (labor, materials, etc.) ***	$24,500	$36,000
Project Management/Report Writing	$1,500	$1,500
Travel	N/A	N/A
Decommissioning/Site Restoration	$900	$734
Natural Gas (therms)***	$5,000	N/A
Shipping	$538	$538
Total	**$111,278**	**$99,118**

Site 2 Project Itemized Costs	Projected Costs	Actual Costs
Plug Power System Lease Cost	$50,000	$45,000
Service contract (replacement stacks)	$20,000	$20,000
Installation (labor & materials)*	$12,000	$3,550
Thermal Recovery (mechanicals in place)	N/A	N/A
Performance Monitoring	$1,200	$1,156
Maintenance (labor, materials, etc.) **	$24,500	$36,000
Project Management/Report Writing	$1,500	$1,500
Travel	N/A	N/A
Decommissioning/Site Restoration	$900	$725
Propane Gas (gallon cost)	$5,000	$10,787
Propane tank set up fee	$200	$147
Shipping	$538	$538
Total	**$115,838.00**	**$119,403**

** Costs to install underground piping/wiring was incurred during the prior H-Power fuel cell installation - see note below.*
*** Twelve month full service maintenance contract with Logan Energy.*
**** Base Utilities did not charge for natural gas consumption as part of their commitment to the fuel cell demonstration and technology advancement.*

Note: Prior to the installation of the two Plug Power fuel cells, there were two H-Power fuel cells. Those costs related to the installation of underground conduit and wires, piping, water treatment, fuel connection, service panel circuit modifications and sub-panel installation were invoiced when the H-Power units were installed. The electrician's fee for the initial installation, labor and materials, was $12,690. The plumber/HVAC fee, which included fuel connections and thermal recovery applications, totaled $8,709. The initial total site preparation cost was $21,399 compared to $7,100 for the second installation in order to accommodate the Plug Power units. The lower cost for the installation of the two Plug Power fuel cell units clearly illustrated the ease of changing out one PEM fuel cell for another, especially when different manufacturers were involved.

13.0 Milestones/Improvements

The two installations at Patuxent River Naval Air Station pushed the limits of the current prototype units from Plug Power. The whole purpose behind the CERL grant was to demonstrate and accelerate the PEM fuel cell adaptation to real world environments. That mission was accomplished and experience gained has been incorporated into next generation prototype units. Listed below are the comments provided directly from Plug Power as to the milestones achieved during this demonstration.

1. Endurance - First Plug Power fuel cells to run continuously at 5kw for an entire twelve-month evaluation period in real world conditions.

2. Software – Software improvements enabled the systems to operate longer between failures and automated many processes that previously required manual intervention or a visit to the site. For example, addition of an auto-restart function and the ability for Plug Power to call into a system to check status. In earlier versions of software, communication was one-way only – the system would transmit data to Plug Power only. This test enabled Plug Power to evaluate the two-way communication format.

3. Notification - Software was developed and installed on the Technical Support Line server to notify Plug Power personnel when a system had shut down via text messaging through a cell phone. This process improved response time, lowered down time, increased customer confidence, reduced customer inconvenience, and improved overall performance.

4. Availability - The two-system fleet finished the 1-year demonstration with an availability of over 90%. The natural gas system had a final availability over 95% and the propane system over 91%. These are significant improvements over previous demonstrations. A system that is 95% available is down for only 18.25 days per year.

5. This was one of Plugs Power's first LPG systems placed in the field. Evaluating reformer hydrogen generation capabilities, catalyst effectiveness, and stack performance has played a major role in improvements made to the next generation of pre-commercial units.

14.0 Decommissioning/Removal/Site Restoration

The decommissioning procedure was easy and straightforward. Navy officials decided not to remove the supporting infrastructure of wires and pipes. They wanted to keep both sites ready for possible future fuel cell installations or an emergency generator. Plug Power maintenance contractor, Logan Energy, was dispatched to the test sites in order to prepare the units for shipment. They drained and recovered all the fluids, disconnected the batteries, and removed the stack. Next the electrician and plumber easily disconnected and removed associated connections and devices pertinent to this installation. Both fuel cells were easily lifted off their respective pads via a SMECO boom truck and transported off site. All wiring and piping at the pad site were secured and weatherproofed in preparation for some possible future installation.

15.0 Conclusions/Summary

This project was a learning experience for all parties. Coordinating contractors, engineering the installation, securing permits, shipping units, and installing them was, at times, analogous to installing a large generator or chiller system. But sometimes it was truly a new experience. Site preparation involved basic wiring and plumbing skills any master electrician or plumber could accomplish. The unknowns were more on the design and operation of the thermal recovery applications. All components were off the shelf devices but the actual operation and performance could not be ascertained until many hours of run time elapsed.

Since both units were set at a 5 kW output, 24/7, the thermal recovery Btuh's could be estimated but not guaranteed. The correct flow rate of thermal recovery fluid, impact from heat loss due to extended buried pipe lengths, and efficiency of heat transfer at load side of loop could not be proven until operation began. Based on data collected and occupant comments both thermal recovery (co-generation) applications worked as designed. The only negative was neither site provided the opportunity to maximize the thermal availability of the fuel cells on a 24/7 basis for all four seasons.

Total availability of both units, 95% for the natural gas unit and 91% for the propane unit, was impressive. The costly aspect was the high service contract fee to pay for the replacement of stacks on a nominal three-month rotation. Plug Power was pushing the prototype units to their limits with the 5 kW settings. All previous field-tested units were set only to the 2.5 kW output limit resulting in long term stack survivability. In conjunction with high stack setting came a high fuel usage requirement. The initial natural gas and propane consumption estimates for each unit's reformer, which also set our fuel cost budget, was too conservative.

Post evaluation discussions with Plug Power confirmed their deep concern with overall reformer efficiency and lessons learned from this demonstration have been incorporated in the advanced prototype.

All systems worked well signified by the high availability percentages. Grid tie option worked as designed with no synchronization problems and proper system disconnect during a distribution fault and a service entrance neutral problem. Power quality was utility grade and complimented by zero customer complaints especially at site 2 where nine computers and a phone system were powered.   In rush current demands, caused by motor starts, and total loads exceeding 5 kW for short durations were handle flawlessly by the on-board inverter/battery bank system.

This demonstration, as previously mentioned, was a second installation at each site. Prior to the Plug Power units being installed, there was an H-Power 5 kW fuel cell at each site. The labor and material costs to construct the infrastructure for the fuel cell connections and thermal recovery were paid for a year before the Plug Power units were installed under the same contract award. A modification to the contract was granted in order to salvage the demonstration and fund the Plug Power installations. The total expenses for the Plug Power portion of the contract, pertinent to this final report, came to a total of $218,521. SMECO and Navy officials are grateful to CERL in allowing the contract to continue with additional funding support. Experience gained from this demonstration clearly has had a beneficial impact in accelerating the PEM fuel cell technology to the next level.

<u>Appendix</u>

1) Plug Power monthly performance data
2) Maintenance logs